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OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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THE EVOLUTION OF ASTRONOMY*

BY F. A. MCDIARMID

AMONG the earliest traditions of every primitive people may be found traces of attempts to explain the elementary phenomena of the heavenly bodies. It could hardly have been otherwise, for the succession of day and night, of summer and winter, and the phases of the moon could not have escaped unnoticed. Few, if any, sciences, can claim such antiquity as astronomy, the elementary stages of which would seem almost coeval with the human race. It is probably safe to assume that the traditional cradle of nations, the Iranian plateau, was also the cradle of knowledge, that every successive migration carried some of its ideas into successive regions, and that the highest development of its science was reached by those who were the last to go.

The process of evolution would begin simply enough. The common phenomena of dawn, sunrise, day, sunset, dusk and night would first attract attention, and their succession be immediately noticed.

* President's inaugural address (abridged), Ottawa Centre, February, 1915.

The varying darkness depending on the light of the moon, as well as the changes in the time of rising and setting, and of the apparent shape of that body would give another longer measure of time, so that besides the day or day-and-night, time came to be reckoned by months or moons, a mode of reckoning still found among savages. Soon, it would be observed by noting the varying length of the day, or the direction of the sun at rising and setting, or the length of the mid-day shadows, that the sun's path also changed from day to day, and that he rose and set farther and farther north from winter to summer, reaching in consequence a higher elevation at noon, and reversed the process from summer to winter. This cycle, obviously coinciding with the course of nature and the fields and woods, gave another and more important time unit.

It is not so easy to fix the length of the year, and the husbandmen, to whom it was a matter of the utmost importance, soon learnt to rely on a class with greater leisure to fix for them the seasons with greater accuracy. The priests naturally claimed and exercised this office, magnifying its importance, elaborating ceremonial sacrifices and thus strengthening their ascendency over the ignorant.

They soon discovered that there is not an exact number of days in a month, or of months in a year, and set themselves to systematic night observations to determine those relations with greater accuracy ; at the same time devising various schemes to evade the difficulty, especially that caused by the length of the month.

They would notice that the moon followed a certain path among the stars, and that the sun's path was nearly identical, and that at the same season of the year the sun's place in that celestial track was always the same. So that zone of the heavens came to be regarded as distinct, and the configurations of the stars in different parts of it were associated with different seasons, and divided into groups called constellations, and given names in order to define the sun's position, that is, the time of year. This zone has long been called the zodiac.

But the primitive astronomers found other celestial objects travelling in the zodiac besides the sun and moon; four very obvious ones, and a fifth whose discovery is prehistoric. Two of these, Venus and Mercury, never appear far from the sun, while the other three, Mars, Jupiter and Saturn, do. They were called wandering stars or planets.

Eclipses of the sun and moon must soon have provided the ancient astronomers with an eclipse cycle; or, at least, with a more accurate value of the length of the month.

The nations of the East, Chaldea, Egypt, India and China, all indulged more or less in the study of astronomy. Chinese records tell of a conjunction of five planets about 2500 B.C., and of a solar eclipse in Scorpio in 2159 B.C., about which it is said that the two government astronomers Ho and Hi were beheaded for failing to predict it. It is further related that as early as 2857 B.C. the emperor recommended the study of astronomy, and made it an important subject, and that a later emperor ordered all astronomical records destroyed. About 1100 B.C., at Lyang, a determination of the obliquity of the ecliptic was made, which confirms the secular diminution of that obliquity; but aside from that we owe them little or nothing.

Indian astronomy is different in that it possesses a system of its own, with tables and rules for calculation, the basis for which claims to be a conjunction of the sun and moon and planets in 3102 B.C. The tables give fairly good results, and are evidence of considerable advance in science; the antiquity of the tables is open to grave doubt, and it is claimed by some that they are not older than the Mohammedan invasion of India.

Egyptian astronomy, again, lays claim to high antiquity. Much has been written as to the astronomical meaning of the Great Pyramid and it is often assumed that its age can be certainly fixed by the circumstance that at some distant period a bright star, now some distance from the pole, was near enough to be used for the pole star, and that its altitude at one of its culminations would then have enabled it to have been observed through a long shaft-like opening in the northern face of the

pyramid. It is also said that the Egyptian temples were oriented to the rising point of certain stars, and if sufficient latitude be given for an inexact observation of a star, some star can usually be found which at some distant date would have answered the purpose. But there is little evidence to warrant us in assuming that the Egyptians had any direct knowledge of astronomy.

In Chaldea we find more confirmed evidence of a knowledge of astronomy. The earliest observations used by Ptolemy were the eclipses observed in Babylon in 721 and 720 B.C. There is, moreover, indirect evidence that in these regions the constellations as known to the Greeks and still in use were first mapped out, as all of them would have been visible there about 2000 B.C., while some constellations, visible further south, as in India or Egypt, were not named so soon. But the progress made in astronomy by the Chaldeans and Babylonians was not very great, as they made little advance in theory.

It is to the Greeks that we owe the first real progress in astronomical science. Thales, of Miletus, the founder of Greek astronomy, taught the Egyptians to measure the heights of their pyramids from their shadows. He taught that the stars shone by their own light, but that the moon receives its light from the sun, that the earth is spherical, and that the year contains 365 days. He is chiefly remembered in connection with the prediction of an eclipse of the sun which put an end to the war between the Medes and Lydians. Soon after this time, the gnomon, a vertical pillar whose least shadow marked the time and altitude of the meridian sun, and from whose midday shadows the obliquity of the ecliptic could be calculated, was first used in Greece. The most commanding figure of the century after Thales was Pythagoras, who suggested, without apparently regarding it as more than a speculation, that the earth revolved around the sun, a doctrine occasionally taught by some of his followers, one of whom, a century later, taught also that the earth revolved daily on its axis.

Meton and Euctemon, at Athens, observed the summer solstice of 432 B.C., the earliest reliable observation of the kind,

but their greatest achievement was the "cycle of Meton." A luni-solar period, after which the sun and moon would be in the same position relatively to the stars, would be of the greatest importance in fixing festivals and had long been sought. The eclipse period of 6585 days, or 223 lunations, a few days more than eighteen years, was known. This sufficed to predict eclipses, but bore no relation to the solar year. Meton, however, hit upon a period of 235 lunations or 19 years approximately, which would bring the sun and moon within a little of the same position relatively to the stars. The discovery was hailed with acclamation at the Olympic games, and the cycle commencing July 16, 433 B.C., was adopted in Greece and its colonies. It was inscribed on brass in golden letters, and is still in use in determining Easter, the golden number being the number of the year in the cycle of Meton.

Meton's system of the calendar required the 235 lunations to consist of 125 months of 30 days, and 110 of 29 days, and the 19 years to consist of 12 years of 12 months and 7 of 13 months. As this was such an advance on previous arrangements, it can easily be understood how inconvenient the others must have been.

About B.C. 350 we come to the earliest extant astronomical work, two books, "Of the Sphere that Moves" and "Of the Risings and Settings of the Stars." They are very elementary geometrical treatises, but they mark the beginning of geometrical astronomy.

Eratosthenes, at Alexandria, invented the armillary sphere, by which positions of celestial bodies could be referred either to the horizon, the equator or the ecliptic, and with it he determined the obliquity of the ecliptic to be 11/160 of a circle, or 23° 51′ 19″·5 in 230 B.C., confirming the secular diminution of the obliquity. With it also he determined the equinox. He also, measured the circumference of the earth which he believed to be a sphere. At noon, at the summer solstice, the sun shone down a well a Syene; while at Alexandra, 5000 stadia to the north, the shadow of a vertical stylus made an angle of 1/50 of a circumference with the stylus itself, hence the circumference of the

earth was inferred to be 50 times 5000 stadia. This was probably fairly accurate, but the stadium differed at different places and times, and we do not know what value was employed.

The most important figure in the astronomical world of ancient times was Hipparchus, who lived about 150 B.C. He represented the motions of the sun, moon and planets by uniform circular motions. He accounted for the apparent variability of the sun's motion by assuming that the earth was not in the centre of the sun's orbit, so that having a line through the earth and the real centre of that orbit, two apses are found, at which the sun's distance is respectively least and greatest (perigee and apogee), and where the motion will appear quickest and slowest. From this hypothesis he determined the position of the perigee, and also the eccentricity or distance of the earth from the centre of the sun's orbit. He constructed the first solar tables giving the position of the sun among the stars. He also prepared tables of the moon's orbit from which could be predicted eclipses. He also made observations on the planets, determining their mean motions with great accuracy.

From a comparison of his observations with those of Aristarchus, made 145 years before, he found that 365¼ days as the length of the year was too long, and he made it seven minutes less, which was still four minutes too great; but a large part of this error was probably due to faulty observations of Aristarchus.

Hipparchus published a star catalogue of 1080 stars, discovered the precession of the equinoxes, and determined its value within 5 per cent. of the truth. We also owe to him the inventing of trigonometry, using chords where sines are now used, and also a method of representing the heavens on a plane, from which he deduced the first notion of fixing geographical positions by lines of latitude and longitude. He also determined longitude by eclipses of the moon.

There was no other astronomer of note till about 130 A.D. when Ptolemy appeared on the scene. Ptolemy, both as an astronomer and geographer, held sway over the minds of almost all the scientific men from his own time down till the 16th–17th

century ; but in astronomy especially he seems to have been not so much an independent investigator as a corrector and improver of the work of his predecessors. In astronomy he depended almost entirely on the labors of Hipparchus. The fundamental principles of his system are, that the earth is the centre of the universe, and that the heavenly bodies revolve around it in circles, and at a uniform rate. The belief that the earth is the centre of the universe was supported by its concordance with the relation of the primary element of which the material world was supposed to be composed. Thus, the earth the most stable of the elements, held the lowest place, and supported water, the second in order ; above water was placed air, and then fire, ether being supposed to extend indefinitely above the others. In or beyond the ether element were certain zones or heavens, each heaven containing an immense crystalline spherical shell, the smallest enclosing the earth and its superincumbent elements, and the larger spheres enclosing the smaller. To each of these spheres was attached a heavenly body, which, by the revolution of the crystalline was made to move around the earth. The innermost sphere was that of the moon, and after it in order came those of Mercury, Venus, the sun, Mars, Jupiter, Saturn and the fixed stars, eight in all. To this system later astronomers added a ninth sphere, the motion of which should produce the precession of the equinoxes, and a tenth to cause the alteration of day and night. This tenth sphere was supposed to revolve from east to west once in twenty-four hours, and to carry the others along with it in its motion ; but there is no explanation of how this is done. As observations of the heavens increased in accuracy it was found that the motions of the heavenly bodies were not uniform, and this was explained as follows :— The acceleration of the sun on one side and the retardation on the other side of his orbit is only apparent, and results from the earth not being in the centre of the sun's sphere. The alternate progression and regression of the planets was accounted for by supposing them to move, not directly with their crystallines, but in a small circle, whose centre was a fixed point in the crystalline, and which

rotated on its axis as it was carried around with the latter; thus, the planet was carried around a small circle, as that circle itself was carried around a larger one. The planet while in the outer portion of its small circle would thus have a forward, and in the inner portion a backward motion. The larger circle was called an eccentric, and the smaller an epicycle. This theory of eccentrics and epicycles satisfied the early astronomers; but further investigations showed its incompleteness, and in later times it was found necessary to explain newly-discovered discrepancies by heaping epicycle upon epicycle till a most complex entanglement resulted. As soon as astronomers came to understand and test the theory of Copernicus, this venerable and disorderly pile of hypotheses crumbled into atoms and sank into oblivion.

For more than 1300 years after the time of Ptolemy there was no figure of outstanding importance till the time of Copernicus, who was born in 1473 A.D., at Thorn, in Poland, Prussia. He had studied medicine, but was so strongly attracted to mathematics, that, having an uncle who was a bishop, he took orders with a view to having enough to live upon while pursuing his scientific studies. He saw that the daily rotation could be as easily explained by the rotation of the earth itself from west to east, as by the rotation of the whole universe from east to west. But having to choose between the simplicity of the one, which Ptolemy had rejected as contrary to common sense, and the obviousness of the other, which Ptolemy had deliberately adopted in spite of the enormous motions it involved, he pointed out that only relative motion is perceived by the senses, and that the air was bound to share the motions of the earth, so that the terrible winds suggested by Ptolemy as a necessary consequence of the earth's rotation would have no existence. Having thus abolished the obviousness on which Ptolemy relied, the simplicity of the opposite system was bound to prevail. Copernicus also saw the extreme improbability of the real existence of Ptolemy's sphere of the stars, which necessitated the assumption that they were all at the same distance from the earth. He deduced that the stars must be of vast size and not mere points, so that their daily revo-

lution about the earth was preposterous. Copernicus evolved his system by which all planets, including the earth, revolved about the sun. His theory was far from perfect, for he still adhered to circular motion, so that as the motion around the sun is not circular, he had to assume a centre for each planetary orbit outside the sun, and all different. He had also to suppose a third motion of the earth to account for the axis always being in the same direction, being misled by the distance of the point to which the axis is directed. Copernicus saw the opposition that his new theory was bound to arouse, and for more than thirty-six years refused to publish it; and he really never saw his theories made public.

Copernicus was a theorist, but his successor, Tycho Brahe, was a practical man. He was first attracted to astronomy by the solar eclipse of 1570, partially visible in Copenhagen. In 1569 he went to Augsburg, where he established an observatory, and here on November 11th, 1572, he saw for the first time the new star, always associated with his name, a bright object in the constellation of Casseopeia, which became as bright as Venus and visible in the daytime, and then faded gradually until March, 1574, when it was no longer in reach of the unaided eye.

The King of Denmark (Frederick II.) equipped an observatory on the island of Hveen, and here Tycho made many observations and discoveries. He computed refraction tables up to 45° altitude and discovered the lunar inequality known as "variation" by observing the moon at all phases instead of just at the quarters. He determined with great accuracy the places of 777 stars.

Tycho Brahe believed that the planets revolved around the sun, yet he supposed the whole universe to turn around the earth. He considered that if the earth really moved around the sun, the stars would show it by apparent displacement, and as the stars to him, (being, as must always be remembered, without telescopic aid,) seemed to be large, he had a different situation to face, of which Copernicus, not an assiduous observer, had no idea, as in order to appear so large and yet be so distant as to show no

annual displacement, or parallax as it is called, the size of the stars must be inconceivably great.

To Kepler was entrusted the reduction of Tycho Brahe's observations, and after twenty years of labor on them, at first under the idea of circular motion, which he was finally forced to abandon, he deduced his three well-known laws. He pointed out the great utility of the eclipses for determining differences of longitude, and the extension of this method to occultations of stars by the moon is still in use.

Contemporary with Kepler, Galileo was born at Florence in 1564. His most important work was the construction of the first telescope. With it he discovered the moons of Jupiter, and the rings of Saturn. He suggested eclipses of Jupiter's satellites as a means for determining differences of longitude.

One of the most prominent figures in the astronomical world of all ages was Isaac Newton, born in 1642, on the day of Galileo's death. He was educated at Cambridge, and at the age of twenty was appointed Lucasian Professor of Mathematics at Cambridge.

Newton's first great discovery was of the composite nature of light and he at once perceived that this had an important bearing upon the construction of the telescope. Those who employed the telescope for looking at the stars had long been aware of the imperfections which prevented all the various rays from being conducted to the same focus. It had been supposed this was due to an imperfectly shaped lens. But when Newton demonstrated that light was composite, it became obvious that a satisfactory refracting telescope was an impossibility when only a single lens was employed, however carefully the lens might be wrought. These difficulties have since Newton's time, to a great extent, been overcome by employing for the objective a compound lens made from two pieces of glass possessing different qualities.

Newton attempted but failed to discover such an achromatic lens, and turned to apply the principle of reflection. He is the father of the reflection telescope; he fashioned a concave mirror

from a mixture of copper and tin, an alloy which gives nearly the lustre of silver. When the light from a star fell on this mirror, its image was produced at the principal focus and this image was examined by a magnifying eye-piece. The telescope tube of his first reflector had a diameter of only one inch, but it was the precursor of whole series of magnificent instruments, each outstripping the other in magnitude. The new telescope for the new observatory at Victoria, British Columbia, will, it is believed, be the finest of the reflection type.

While his researches on light would have sent Newton's name down to posterity as a great scientist it was the discovery of the law of universal gravitation which crowned his illustrious career. It is said that Newton seeing an apple fall from a tree argued as follows :—"The earth attracts the apple ; it would do so no matter how high the tree might be, and the power extends far beyond the highest tree. It would seem that this power which resides in the earth extends throughout space." On the principle of gravitation Newton was able to explain the movements of the moon and applying the same law he saw how the earth should be guided and controlled by the supreme attractive power of the sun. Also, the movements of the planets could be explained to be consequences of solar attraction. He also showed that Kepler's Laws were simply consequences of this principle. Newton explained the tides as a consequence of the attractive power which the moon and sun exert upon the oceans.

But probably the most signal of Newton's applications of the law of gravitation was connected with certain irregularities in the movements of the moon. In its orbit around the earth the moon is, of course, mainly guided by the attraction of the earth. If there were no other body in the universe, then the centre of the moon must necessarily perform an ellipse, with the earth in one focus of the ellipse. But the sun disturbs this arrangement ; it attracts the moon, and in consequence the moon's movements with regard to the earth are seriously affected by the influence of the sun. It is not allowed to move exactly in an ellipse, nor is the earth exactly in the focus. How great

was the achievement of Newton will be appreciated when it is realized that he not only had to determine from the law of gravitation the nature of the disturbance of the moon, but he had actually to construct the mathematical tools by which alone such calculations could be effected.

On the continent of Europe, Newton had plenty of opposition; his theories were combated by many of the leaders in the scientific world. Nevertheless, his opponents by their investigations and observations were in reality working to confirm his theories. In one conspicuous instance Newton's theory had been supposed to fail, his determination of the motion of the moon's perigee being just half the observed quantity, and, of course, this soon attracted attention. Euler, Clairaut and D'Alembert all working on this same problem reached the same conclusion as Newton, but on revising their calculations and taking account of some terms previously neglected, they arrived at a value double the old one and exactly confirmed Newton's law. Laplace and Lagrange both continued work along the lines Newton had laid down, and it is to this age that we owe much of our present knowledge of mathematics and astronomy.

A very important event, the establishment of the Greenwich Observatory, took place in 1675, and Flamsteed was the first Astronomer Royal. At first he was obliged to work with very poor equipment, being unable even to obtain a meridian instrument for the fundamental observations of star places. Eventually Flamsteed published the best star catalogue of that day, but his work was hampered through lack of financial assistance. He was succeeded by Halley, who became famous by the discovery and determination of the orbit of the comet which bears his name. Halley was followed at Greenwich by Bradley, one of greatest of the long line of Astronomers Royal who have been connected with the Greenwich Observatory.

Bradley made two great discoveries which placed him in the forefront of astronomical discoverers. It had long been recognized that as the earth described a vast orbit nearly two hundred millions of miles in diameter, in its annual journey around the

sun, and the apparent places of the stars should alter, to some extent, in correspondence with the changes in the earth's position. The nearer the star the greater the shift in its apparent place in the heavens, since it is seen from different positions in the earth's orbit. Bradley, on examining different stars found that some had an annual variation in latitude only, some in longitude only, and others described an elliptical path, as both latitude and longitude varied. Since all of them, however, seemed to show an annual period, Bradley concluded it was the earth's motion around the sun that really caused the apparent motion. This annual effect he soon attributed to the combined effect of the velocity of light and that of the earth. This phenomenon, called aberration, became apparent in the observations. Applying the correction for aberration he found still another residual error which increased for about nine years, and then diminished for the same period. This suggested the primary cause to be the varying position of the moon's orbit, which has a period of rather more than eighteen years, and the result of which is to cause a slow nutation of the earth's axis in the same period. Bradley's great work at Greenwich, the foundation of stellar astronomy, was long almost ignored, until his numerous observations were reduced by Bessel, forming the "Fundamenta Astronomia," published many years after Bradley's death.

Another great man of the 18th century, Sir William Herschel, was the pioneer of modern descriptive astronomy. He discovered the planet Uranus and two of its satellites, and also two satellites of Saturn. He studied the nebulæ and classified many double stars. His only assistant was his sister, Caroline, who after his death prepared his observations of nebulæ and clusters for publication.

Of Herschel's pioneering work in the skies, Miss Agnes Clerke in her "History of Astronomy" says:—"To explore with line and plummet the shining zone of the Milky Way, to delineate its form, to measure its dimensions, and search out the

intricacies of its construction was the primary task of his life, which he never lost sight of, and to which all his other investigations were subordinate. He was absolutely alone in this bold endeavor. Unaided he had to devise methods, accumulate materials and sift out results. Yet it may safely be said that all the knowledge we possess on this sublime subject was prepared, and the greater part of it anticipated by him."

Up to the beginning of the 19th century, Greenwich was the great astronomical centre of the world. Greenwich observations were the standard of reference all over Europe. In 1767 the *Nautical Almanac* was founded under Dr. Maskelyne. However, the entry of Fraunhofer and Bessel upon the scene gave Germany a high place in the astronomical world.

Bessel, in 1813, took charge of the Königsberg Observatory, the first efficient observatory in Germany, and labored there for thirty-two years. He soon became one of the prominent figures in the field of astronomy. Many of the earlier astronomers had not systematically reduced their observations, omitting many little details which were considered of small importance. Bessel's first work of importance was an investigation of the precious series of observations made by Bradley from 1750 to 1762. This investigation involved the formation of the theory of errors of each of Bradley's instruments, and a difficult and delicate inquiry into the true value of each correction to be applied, Bessel's final improvements in the methods of reduction not only constituted an advance in accuracy, but afforded a vast increase of facility in application and were at once universally adopted.

Fraunhofer, working at Munich, constructed for the Königsberg Observatory the first heliometer, the property of which instrument is the separation by a strictly measureable amount of two images of the same object. If a double star, for instance, be under examination, the two half lenses into which the object glass is divided are shifted until the upper star in one image is brought into coincidence with the lower star in the other, when their distance apart becomes known by the amount of motion given. Fraunhofer had also constructed an object glass of exquisite

quality and finish, 9½ inches in diameter and 14 feet focal length. This was secured by Struve for the Russian Government, and mounted in the great Dorpat Refractor late in 1824, and was employed by Struve in his great researches.

Bessel, with the aid of the new heliometer, continued his search for star parallax, and in 1838 made known the result of one year's observations, showing for the star 61 Cygni a parallax of about one-third of a second. Later observations considerably increased this to nearly one-half a second. Other observers about this time were working on parallax, Struve at Dorpat, and Henderson, a native of Dundee, afterwards Astronomer Royal of Scotland, at the Cape of Good Hope. Henderson worked on the double star α Centauri and found for it a parallax of nearly one second of arc.

Thus from three different quarters, three successful and almost simultaneous assaults were delivered upon a long-beleagured citadel of celestial secrets. Later work has shown that the majority of the stars are too far distant to show even the slightest traces of optical shifting from the revolution of the earth in its orbit.

In 1835, under the direction of Struve, the great Pulkowa Observatory was commenced, and completed in 1839, when Struve was installed as director. The chief instrumental glory of this new observatory was its 15-inch refractor made by Merz and Mähler.

Another outstanding figure during the first half of the 19th century was John Herschel, the son of Sir William Herschel. Sir John Herschel used his father's methods and instruments in studying the heavens. His first publication was given in 1833 to the Royal Society in the form of a catalogue of stars in order of their right ascension. He included in this new catalogue between 3000 and 4000 stars of the northern heavens In 1834 he established, near the Cape of Good Hope, an observatory at Feldhausen, where at his own expense he worked for four years. He completed his observations of the southern sky, and in 1847, nine years after his return from the Cape, he published " Astro-

nomical Observations made at the Cape," being the completion of a telescopic survey of the whole surface of the heavens started in 1825.

Looking back over the first fifty years of the century we see that great steps forward have been taken. Not alone was acquaintance with individual members of the cosmos extended, but their mutual relations, the laws governing their movements, their distances from the earth, masses, intrinsic lustre, had begun to be successfully investigated. Begun to be! for only regarding a scarcely perceptibly minority had even approximate conclusions been arrived at. Nevertheless, the whole progress of the future lay in the beginning; it was the thin edge of the wedge of exact knowledge. The principle of measure had been substituted for that of probability; a basis had been found large and strong enough to enable calculations to ascend from it to the sidereal heavens; and refinements had been introduced, fruitful in performance, but still more in promise. Thus, rather the kind than the amount of information collected was significant for the time to come—rather the methods employed than the results actually secured, rendered the first half of the 19th century of epochal importance in the history of our knowledge of the stars.

One other event of this half of the century cannot be allowed to pass unnoticed. The discovery of the planet Neptune was one of the notable achievements of that era, and proved beyond the shadow of a doubt the truth of Newton's law of gravitation. The history of the wonderful calculations of Adams in England and Leverrier in France and their remarkable verification by the telescope has often been told.

For many years, up to the time of Newton, there was no great advance, but since his time great steps forward have been taken, and during the last half century the growth has been far more rapid than during any other period of the world's history. In the limited time at our disposal, it would be unwise to attempt to describe the growth in any detail. The establishing of well equipped observatories all over the world, the giant reflecting

and refracting telescopes, the introduction of the spectroscope, the use of photography, have all combined to aid the astronomer in his search after the mysteries of the starry regions that to the unaided eye are things of so much interest. What discoveries may be made, or what profound secrets of the universe may be unravelled we cannot predict, but surely when the pioneers made such great discoveries with the limited means at their disposal, it is not too much to hope that there are great stores of knowledge waiting to be unfolded. It is this that leads the astronomer on in his sometimes monotonous grind of tedious observations and complicated reductions.

DOMINION OBSERVATORY,
OTTAWA, CANADA.
February 5, 1915.

THE ORBIT OF μ PERSEI

By J. B. Cannon

THE star μ Persei ($\alpha = 4^h\ 8^m{\cdot}6$, $\delta = +48°\ 11'$) was announced a spectroscopic binary in *Lick Observatory Bulletin* 199, which gives seven measures having a range of 39 km. It was under observation here during the years 1913, 1914 and 1915. Forty-eight plates in all were taken, fourteen in 1913, eighteen in 1914 and the remainder in 1915. On these forty-eight plates the following work is based. The period, being exceptionally long, — 284 days — cannot be considered very closely defined, as the epoch between the first of the Lick observations and the last of ours covers only a little over 22 periods. The spectrum is of *G* type and a good number of lines were employed most of which admit of fairly close measurement. Table I. gives the lines used and the elements to which they are due. The wave-lengths were computed by averaging the line-residuals in all plates.

TABLE I.—LINES MEASURED IN μ PERSEI

Wave-Length	Element	Wave-Length	Element	Wave-Length	Element
4861·334	Hydrogen	*4340·749	Hydrogen	4198·494	Iron
4583·963	Iron	*4325·687	Iron	4143·749	Iron
*4572·082	Titanium	*4314 848	Iron-Titan	4136·685	Iron
*4549·759	Iron	4294·301	Iron	4131·047	Silicon
4481·400	Magnesium	*4289·972	Chrom-Titan	4128·075	Silicon
4468·987	Titanium	*4271 746	Iron	*4101·904	Hydrogen
4437·718	Iron	4260·569	Iron	4071·901	Iron
*4415·405	Iron	4233·370	Mangan-Iron	4063·956	Iron
*4404·986	Iron	4227·213	Iron	*4045·909	Iron
4395·548	Titan-Ven.	*4215·780	Iron	*4005·421	Iron
*4351·745	Chrom-Mag.	4202·161	Iron		

*Those marked with an asterisk are the lines most generally used. The others are used only in a few plates.

Table II. gives the Lick Observations, Table III. the Ottawa Observations, the phase being from the final periastron date and the residual from the final curve.

TABLE II.—LICK OBSERVATIONS

Date	Julian Day	Phase	Velocity	Residual
1897, December 23·808	2,414,282·808	184·84	− 8·1	+ 3·7
1898, February 2·721	323·721	225·75	− 6·8	+ 0·1
October 26·960	589·960	207·99	− 9·1	+ 1·9
1905, October 10·900	2,417,129·900	191·93	− 9·3	+ 3·7
1908, February 26·673	998·673	208·70	− 10·8	± 0·0
1910, September 1·001	2,418,916·001	274·03	+ 15·0	+ 0·6
October 7·940	952·940	26·97	+ 28·4	+ 0·3

TABLE III.—OTTAWA OBSERVATIONS

Plate	Obs.	Date	Exp.	Julian Day	Phase	Velocity	Wt.	O–C
		1913	m					
5329 (*a*)	H	Jan. 28	75	2,419,796·60	18·62	+ 24·0	8	− 1·8
5338	P′	Feb. 3	90	802·70	24·73	+ 24·0	7	− 3·0
5349	H	Feb. 6	88	805·66	27·69	+ 30·3	8	+ 2·5
5383	H	Feb. 18	60	817·56	39·59	+ 30·2	7	+ 1·3
5391	C	Feb. 24	60	823·57	45·60	+ 32·5	7	+ 3·7
5415	C	Mch. 7	65	834·53	56·56	+ 27·0	6	− 0·6
5426	C	Mch. 11	65	838·54	60·57	+ 23·8	7	− 3·0
5696	G	Sept. 24	65	2,420,035·90	257·93	+ 5·5	6	+ 1·3
5757	C	Oct. 6	60	047·90	269·93	+ 13·4	5	+ 0·9
5782	P′	Oct. 13	67	054·89	276·92	+ 19·9	5	+ 4·4
5795	G-P′	Nov. 5	60	077·75	15·78	+ 20·6	5	− 4·5
5803	Y	Nov. 6	80	078·66	16·69	+ 22·1	4	− 3·1
5864	P′	Dec. 31	55	133·68	71·71	+ 25·3	6	+ 1·1
		1914						
5871	Y	Jan. 1	45	134·62	72·65	+ 20·5	7	− 3·6
5886	P′	Jan. 12	40	145·71	83·74	+ 15·5	5	− 9·7
5921	P′	Feb. 9	60	173·63	111·66	+ 6·7	7	− 2·7
5943	P′	Feb. 16	60	180·58	118·61	+ 9·7	6	+ 3·0
5956	C	Feb. 23	60	187·01	125·64	+ 5·6	5	+ 1·9
5975	C	Mch. 13	25	205·52	143·55	− 10·4	2	− 7·6
5986	C	Mch. 20	60	212·59	150·62	− 8·5	4	− 3·2
6387	C	Sept. 16	60	392·81	46·84	+ 36·7	4	+ 7·9
6449	C	Sept. 30	60	406·80	60·83	+ 40·9	4	+ 14·1
6501	H	Oct. 13	60	419·86	73·89	+ 28·1	5	+ 4·3
6518	P′	Oct. 21	55	427·94	81·97	+ 18·0	7	− 8·0
6572	C-P′	Nov. 23	65	460·75	114·78	+ 8·6	4	+ 0·2
6583	C	Nov. 27	107	464·77	118·80	+ 3·1	3	− 3·6
6592	C	Dec. 4	85	471·69	125·72	+ 1·7	4	− 2·0
6616	C	Dec. 11	80	478·68	132·71	+ 0·8	5	− 0·1

Plate	Obs.	Date	Exp.	Julian Day	Phase	Velocity	Wt.	O-C
6628	Y	Dec. 15	55	2,420,482·68	136·71	+ 0·2	3	+ 0·7
6654	Y	Dec. 22	60	489·66	143·69	- 9·6	3	- 6·8
6666	Y	Dec. 30	60	497·52	151·55	4·2	6	+ 1·3
		1915						
6693	C	Jan. 8	75	506·68	160·71	- 2·4	7	- 5·6
6719	C	Jan. 20	63	518·56	172·59	- 2·6	5	+ 7·9
6730	Y	Jan. 24	55	522·57	176·60	- 17·6	4	- 6·6
6734	C	Jan. 25	50	523·65	177·68	- 8·5	3	+ 2·5
6744	P'	Jan. 27	75	525·69	179·72	11·7	6	- 0·3
6761	P'	Jan. 30	60	528·50	182·53	- 11·8	7	- 0·1
6782	C	Feb. 12	55	541·60	195 63	- 13·5	7	- 1·6
6787	H	Feb. 17	55	546·55	200·58	- 11·1	7	+ 0·6
6818	Y	Feb. 28	60	557·55	211·58	- 10·2	8	+ 0·3
6827	H	Mch. 3	55	560·56	214·59	- 8·9	8	+ 0·9
6855	H	Mch. 11	60	568·57	222 60	- 13·6	7	- 5·9
6863	Y	Mch. 14	55	571·56	225·59	- 10·6	7	- 3·8
6883	H	Mch. 22	50	579·57	233·60	- 2·6	8	+ 1·2
6892	H	Mch. 29	44	586·55	240·58	+ 4·1	7	+ 5·5
6905	H	Apr. 7	60	595·54	249·57	+ 4·4	8	+ 1·9
6923	H	Apr. 14	64	602·54	256·57	+ 3·2	6	+ 2·8
6966	H	May 6	60	624·56	278·59	+ 14·6	3	- 2·1

Eleven normal places were formed which are given in Table IV. with the mean Julian Day, mean phase, velocity, weight and residual.

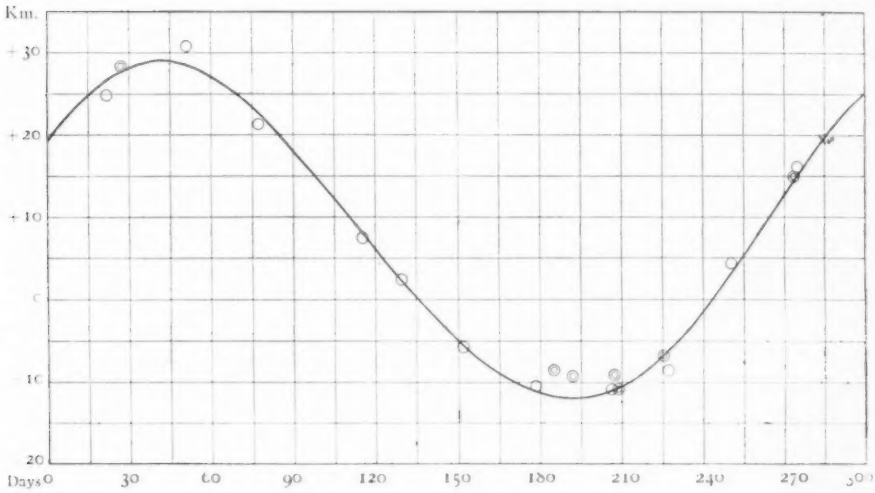
TABLE IV.—NORMAL PLACES

No.	Julian Day	Phase	Velocity	Weight	Residual
1	2,419,958·950	50·87	+ 30·8	4	+ 2·3
2	2,420,248·930	77·03	+ 21 3	3·5	- 1·3
3	276·812	115·44	+ 7·4	2	- 0·4
4	392·131	129·69	+ 2·3	2	+ 0·2
5	439·197	152·50	- 5·7	2·5	- 0·3
6	524·307	178·34	- 10·5	2·5	+ 0·6
7	552·066	206·10	- 10·8	3·5	+ 0·4
8	573·519	227·55	- 8·6	2·5	- 2·2
9	470·400	250·65	+ 4·3	3	+ 1·2
10	183·669	274·61	+ 16·2	1·5	+ 1·3
11	2,419,879·385	21·54	+ 24·8	3·5	- 1·9

Elements were determined graphically and a least squares solution was carried through. The values resulting from this solution, and the graphical values are given in the table below. The probable errors are added in the last column.

SUMMARY

Element	Graphic	Corrected	Probable Error
γ	7·92 km.	7·83 km.	± ·36 km.
K	21·50 km.	20·52 km.	± ·09 km.
e	·1	·0615	± ·0313
ω	300°	301°·99	± 18·04
T	2,420,058·70 J. D.	2,420,061·97 J. D.	± 14·18 days
$a \sin i$		80,000,000 km.	



VELOCITY CURVE OF μ PERSEI

In the curve the single circles represent Ottawa normal places, and the double circles Lick observations.

DOMINION OBSERVATORY,
OTTAWA, CANADA,
June 1915

NOTES FROM THE METEOROLOGICAL SERVICE

Summary Report of the Weather in Canada

August, 1915

Temperature.—The temperature was above the average from the British Columbia coast line to the western portion of Lake Superior. Elsewhere in the Dominion it was below the average, except in a small portion of Quebec and the Maritime Provinces, where it was from average to one degree above. The chief positive departures were eight degrees at Medicine Hat, seven at Edmonton, six at Battleford, and five at Calgary and Vancouver, and the chief negative departures were three degrees at White River, Southampton and Ottawa.

Precipitation.—The rainfall for August was remarkable for the excessive amount which fell over all portions of Ontario, except in very far northern districts. The fall varied from 5 to nearly 10 inches, the record being broken in many localities. Port Dover recorded 9·57 inches; Agincourt, 9·86 inches; Wexford, 8·21 inches; Alton, 8 inches; Paris, 7·10 inches; Renfrew, 7·20 inches; Ottawa, 7·50 inches; Watford, 7·42 inches; while the fall of 8·16 inches at Toronto is the largest amount for August recorded since the observations have been taken which is from 1840. On the other hand outside of a rainfall much above the average quantity on the south and east coasts of Nova Scotia and with an amount slightly above the normal at a few isolated places in Quebec, Northern Alberta and the interior of British Columbia, the rainfall was everywhere deficient, especially in the Western Provinces where the negative departure varied from 1 to over 2 inches.

Temperature for August, 1915

Station	August		Station	August	
	Highest	Lowest		Highest	Lowest
Yukon			Huntsville	85	34
Dawson	76	30	Kenora		
British Columbia			Kinmount		
Atlin	72	36	Kingston	85	41
Agassiz	98	45	London	89	35
Barkerville	77	36	Lucknow	84	32
Kamloops	95	50	Markdale	83	34
New Westminster	92	50	North Gower	92	32
Prince Rupert	76	48	Oshawa	87	38
Vancouver	89	51	Ottawa	83	40
Victoria	88	48	Paris	87	40
Western Provinces			Parry Sound	86	37
Battleford	95	38	Peterboro'	86	36
Calgary	88	46	Port Arthur	89	34
Edmonton	87	43	Port Burwell	82	39
Medicine Hat	92	48	Port Dover	83	39
Minnedosa	90	26	Port Stanley	84	36
Moose Jaw	95	38	Queensborough	85	33
Oakbank	95	28	Ronville	83	33
Portage la Prairie	92	34	Southampton	78	39
Prince Albert	86	32	Sundridge		
Qu'Appelle	95	35	Stonecliffe	88	35
Regina	95	38	Stony Creek	85	41
Saskatoon	96	32	Toronto	87	40
Souris	91	31	Uxbridge	86	35
Swift Current	94	38	Wallaceburg	86	36
Winnipeg	94	32	Welland	84	42
Ontario			White River	80	21
Agincourt	89	37	*Quebec*		
Aurora	83	34	Brome	82	32
Bancroft	84	33	Father Point	72	38
Barrie	85	38	Montreal	87	45
Beatrice	80	32	Quebec	85	38
Berlin	87	36	Sherbrooke	84	35
Bloomfield	87	40			
Brantford	88	35	*Maritime Provinces*		
Chapleau	82	28	Charlottetown	82	46
Chatham	90	38	Chatham	88	38
Clinton	81	35	Dalhousie	85	37
Collingwood	80	39	Fredericton	85	36
Cottam	85	36	Halifax	86	42
Georgetown	82	38	Moncton	83	37
Goderich	81	38	St. John	75	44
Gravenhurst	84	32	St. Stephen	86	33
Grimsby	86	43	Sussex	83	33
Guelph	85	36	Sydney	82	40
Haliburton	88	30	Yarmouth	77	42

MAGNETIC OBSERVATIONS

July and August, 1915

The magnetic curves obtained at Agincourt during July indicate normal conditions in the Magnetic Forces for the greater part of the month. On the night of the 1st there occurred the largest disturbance for the month, which was most pronounced in the Declination and Vertical Force. The changes in direction and force were generally slow and of small amount. At 22^h 37^m, however, the Westerly Declination began to increase and in half an hour had changed through 59′, at the same time the Vertical Force decreased 100γ, whilst there was no corresponding movement in the Horizontal Force. Small disturbances were also recorded on the 6th, from the 8th to the 12th and from the 22nd to the 30th.

During August departures from normal conditions were recorded more frequently and were of greater amount. The larger disturbances occurred on the 2nd, 6th, 26th and 28th. The rest of the month, with the exception of the period from the 12th to the 16th, was lightly disturbed. The magnetic storm of the 2nd has the appearance, as though a large force had been applied to and withdrawn gradually from the earth's normal field at intervals of several hours producing large bays in the curves. It began in the afternoon of the 1st and lasted until midnight of the 2nd. The storm of the 6th was of short duration, being from 16 hours of the 6th until midnight, but was very active. Short sharp movements characterise this storm in all three elements. The most pronounced disturbance of the month began in the afternoon of the 25th and continued until the morning of the 27th. Some very rapid changes of force occurred, notably at 19^h 37^m when the Horizontal Force in 5 minutes increased 185γ and in the next 10 minutes decreased 259γ, at the same time the W. Declination decreased 31′ and then increased 44′. The Vertical Force had gradually increased from 18^h to 19^h 40^m by 174γ and in the next 13 minutes decreased 228γ. The remainder of the storm was marked by rapid pulsating changes of force of

small magnitude. The disturbance of the 28th was of the same character as that of the 2nd, but only lasted from 20^h of the 27th to noon of the 28th.

In the data given with the copies of the magnetic records on page 364 of the September, 1915, number of the JOURNAL, the scale values are erroneously given, not having been corrected for the reduction in size of the copy from the original to which those values applied. The corrected values are for D, $1^{mm} = 4'{\cdot}40$; H, $1^{mm} = 0{\cdot}0001594$; V, $1^{mm} = 0{\cdot}0001918$.

July, 1915		D. West	H	V	I
		° ′			° ′
	Mean of Month	6 28·3	0·16034	0·58646	74 43·0
	Maximum	6 54·1	0·16108	0·58698	
	Date of Maximum	1	22	9	
	Minimum	5 55·1	0·15927	0·58507	
	Date of Minimum	1	1	1	
	Monthly Range	0 59·0	0·00181	0·00191	
Mean Daily Amplitude	From hourly readings	0 13·5	0·00048	0·00013	
	From Means of Extremes	0 19·2	0·00071	0·00036	

August, 1915					
		° ′			° ′
	Mean of Month	6 28·5	0·16027	0·58644	74 43·2
	Maximum	6 46·8	0·16223	0·58836	
	Date of Maximum	28	25	25	
	Minimum	5 46·0	0·15867	0·58518	
	Date of Minimum	25	6	25	
	Monthly Range	1 00·8	0·00356	0·00318	
Mean Daily Amplitude	From hourly readings	0 14·4	0·00052	0·00015	
	From Means of Extremes	0 22·2	0·00092	0·00053	

H and V are expressed in C. G. S. Units.

I is the Mean of all Dip observations made during the month with the Earth Inductor, without regard to the time of day at which they were made. Two observations are usually made each week, one in the morning near the time of maximum Dip and the other in the afternoon near the time of minimum Dip.

Earthquake Records by the Milne Seismograph

TORONTO

R. F. Stupart, Director.

P.T. = Preliminary Tremors. L.W. = Large Waves. A.C. = Air Currents.
Time is Greenwich Civil Mean Time, 0 or 24 h = midnight.

No.	Date 1915		P. T. Comm.		L.W. Comm.		Max.		End		Max. Amp.	Durat.		Remarks
			h	m	h	m	h	m	h	m	mm.	h	m	
1493	July	20	16	4·9	16	9·8			16	15·0	0·1	0	10·1	
1494	"	22			4	30·4			4	40·7	0·1	0	10·3	
1495	"	25	21	4·3	21	16·6	21	22·5	21	51·2	0·4	0	46·9	
			S 21	8·6										
1496	"	31	1	41·8	2	1·0	2	11·7	5	20·8	3·4	3	39·0	L. W. continued for a long time.
			S 1	51·8			2	15·1			3·8			
							2	17·4			3·2			
1497	Aug.	3	13	27·3	13	43·5								
1498	"	3	14	0·2	14	13·1	14	24·5	15	46·9	2·2			
1499	"	6	13	44·8	13	58·9	14	8·4	14	55·1	0·8	1	10·3	
			S 13	51·0										
1500	"	7	15	31·7	15	46·7	15	49·5	16	11·4	0·8	0	39·7	
			S 15	39·9										
1501	"	10	2	40·0	2	45·6	2	47·3	2	59·4	0·8	0	19·4	
			S 2	44·3										
1502	"	11			9	52·3			9	59·5	0·05			
1503	"	16	1	15·1	1	30·2	1	33·8	2	42·0	0·3	1	26·9	
					1	31·9	1	50·4			0·3			
1504	"	19	0	21·4	0	45·9			1	45·5	0·2	1	24·1	
					1	7·1								

Period = 18 seconds. 1 mm. = 0″·59.

VICTORIA, B. C.

F. N. DENISON, SUPERINTENDENT.

No.	Date 1915	P.T. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Durat.	Remarks
		h m	h m	h m	h m	mm.	h m	
1494	July 20	16 7·8		16 7·9	16 12·9	0·1	0 5·1	Readings uncertain.
1495	" 22	4 25·9	4 36·4	4 40·9	4 55·4	0·3	0 29·5	
1496	" 25	20 59·8 S 21 1·8	21 2·8	21 3·8	21 18·3	0·5	0 18·5	
1497	" 31	1 39·8 S 1 46·4	1 50·6	1 57·8	5 11·8	3·8	3 32·0	Near Kurile Islands.
1498	Aug. 3	13 34·4 S 13 51·8	13 59·4	14 8·9	16 49·9?	1·5	3 15·5	9600 km.
1499	" 6	13 40·3	13 49·3	13 52·3	14 54·3	0·5	1 14·0	
1500	" 7	15 27·4 S 15 46·9	15 52·4	15 56·4	16 20·4	0·5	0 53·0	10500 km.
1501	" 10	2 45·5?	2 51·5	2 59·5	3 23·0	0·3	0 37·5	
1502	" 16	S 1 9·4?	1 15·4	1 16·4	2 48·9	0·4		
1503	" 18	14 05·0	14 05·3		14 08·0	0·1	0 3·0	80 km. Eq. felt in Victoria and along Fraser Valley.
1504	" 19	1 3·0 S 1 16·0	1 22·0	1 23·0	1 43·0	0·1	0 40·0	1300 km.

Period = 18 seconds. 1 mm. = 0″·54

J. V.

REVIEW OF PUBLICATION

Publications of the Astronomical Observatory of the University of Michigan. Volume I., pp. 73-206.

In the first part of the volume, issued some two or three years ago, a general account of the observatory, its history, buildings and instruments was given by the Director, W. J. Hussey. A description, more in detail, was given by Curtiss of the single prism spectrograph and there was included also a record by Mitchell of the earthquakes up to 1912.

The present portion indicates the improvement to the equipment and some of the principal investigations in progress. A number of minor improvements to the telescope and spectrograph have been carried out in the observatory workshop and some 3200 spectrograms have been secured with it since it was installed in May, 1911. Announcement is made of funds donated for the purchase of a 24-inch refractor.

Observations of 312 double stars discovered with the 17-inch refractor at La Plata Observatory in the year 1911 are given by the Director, who is also the Director of the southern observatory. Some of the position angles and distances are approximate only as no micrometer was then available. Since it has been received measures have been made by Hussey on about 180 southern double stars.

Observations of the more important comets from 1908 to the present are given, many of them being observed both at Ann Arbor and at La Plata.

Eighteen earthquake records for 1912 are given by Mitchell

and fifteen for 1913 by Merrill, with the necessary remarks. Merrill also contributes a note on two bright line stars Ψ Persei and β Monocerotis, both of which have constant velocities; the former − 0·1 km. and the latter + 22·4 km. per sec. The mean velocity of Maia (20 Tauri) from 40 measures is + 6·4 km. and as the range in the measures is only 16 km. it is uncertain whether the star is a spectroscopic binary or not. Mellor investigates with the single prism spectrograph, the suitability of the lines in the titanium spark for radial velocity work.

One of the principal papers included is by Curtiss, on "A Determination of the Visual Light Curve of Beta Lyræ." Though the discovery of this variable dates back some 150 years and much work has been expended upon it, yet, to a considerable extent, it is an unsolved problem and as it is the brightest of a certain class of variable stars the importance of studying it is seen.

Curtiss employed an adaptation of Argelander's visual method taking but two stars γ and δ Lyræ for comparison instead of a number. The former star is nearly equal to the variable at maximum, while the latter is a little fainter than the variable at minimum. 612 observations, secured in the years 1907-1913, were treated, first each year separately, and no variations in the curve being established they were then grouped into a mean curve. A correction of + 0·15 days for the time of principal minimum, as predicted by Pannekoek's formula, was determined. Taken in connection with other curves from Argelander down no real changes in the form of the light curve are noted, the minor irregularities being ascribed to personal or systematic errors of the observers. The relative intervals between the principal phases cannot be said to change, though there would seem to be a slight decrease in the brightness at secondary minimum.

While possibly nothing new has been brought out in the work the author has shown that the use of two comparison stars yields results comparable in accuracy with those where many comparison stars are used and he has set a very high standard in estimating brightnesses by the unaided eye.

Another paper by Curtiss is on "Characteristics of Cepheid Variables" dealing with the data available to August, 1913. Taking Luizet's list of 93 stars he finds confirmation of the two groupings of periods mentioned by others; those having preference for periods four to eight days and those with periods less than two days. The relationship between the periods and corresponding magnitude ranges is dwelt upon, but he suggests that possibly future discovery will alter conclusions that might be drawn from a limited list. A preliminary relationship between period and velocity range is suggested, *viz.*, $P = 2000/K^2$ but the data seems rather meagre. Out of ten velocity curves of these variables available at that time, two were definitely known to have irregularities, $-\zeta$ Geminorum and W Sagittarii. He discusses these irregularities from the standpoint of rotational effects: in the former the theory does not seem to fit, in the latter it does seem to suit.

His last paper is on "Delta and Epsilon Orionis." It is devoted to a discussion of their total light, spectra and radial velocities. A least squares solution of Hartmann's observations of δ Orionis is made and the results compared with those obtained from 74 spectrograms secured at Ann Arbor. No changes in the velocity curve are established in the interval of eleven years. The velocity of the stationary H and K lines is -7 km. The variable radial velocity of ϵ Orionis announced by Frost is confirmed by 30 measures at Ann Arbor but as the range is small (11 km.) no period is arrived at.

W. E. HARPER.

ASTRONOMICAL NOTES

THE DIRECTION OF ROTATION OF SUN-SPOT VORTICES.—Whirling storms in the earth's atmosphere, from the extensive and moderate cyclone to the small and destructive tornado, follow a well-known law of rotation : right-handed or clockwise in the southern hemisphere and counter-clockwise in the northern. These directions are easily explained by the increasing eastward velocity of the air from pole to equator. As sun-spots are vortex phenomena, analogous in many respects to tornadoes, it is interesting to inquire as to the law of their rotation, since this may throw light on their nature and origin.

Every sun-spot exhibits a magnetic field, whose polarity is determined by the direction of rotation of the electrons in the spot vortex. To learn the polarity, and hence the direction of rotation, it is therefore only necessary to observe whether the red or the violet component of a spot triplet is transmitted by the polarizing apparatus.

The typical sun-spot group consists of two spots of opposite magnetic polarity, lying on a line which usually makes only a small angle with the solar equator. One of the spots may be replaced by several smaller ones, or even be absent altogether, its place in the latter case being indicated by calcium and hydrogen flocculi. Small companion spots, of either polarity, may attend either member of the pair. The characteristic feature of the group is the presence of magnetic fields, of opposite polarity, in the regions including its eastern and western extremities.

From the best supplementary evidence at present available, the true direction of rotation of a preceding spot vortex in the

low latitude zone is counter-clockwise, corresponding to that of a terrestrial tornado. The opposite direction obtains in the southern hemisphere, as on the earth. But in high latitudes the signs are reversed — a result which is likely to prove significant in future studies of the sun. The complete details of this investigation will be published in the *Astrophysical Journal*—GEORGE E. HALE, Communications from the Mount Wilson Solar Observatory, to the *National Academy of Sciences*, No. 10.

THE ROTATION-PERIOD OF NEPTUNE.—Observing Neptune towards the end of November, 1883, there were two stars of about the same magnitude in the field of view, and it was noticed that while the light of the stars remained steady through the night, or from night to night, the light of Neptune varied considerably. Comparisons continued for a fortnight or so gave a period of rotation of Neptune of about $7^h\ 55^m$, and then the variations suddenly ceased. The observations were published in the *Monthly Notices*, Vol. XLIV., p. 257.

During the recent opposition of Neptune photometric observations were made; the method adopted is such that if two stars given in the catalogue of the Revised Harvard Photometry are compared, and if the magnitude of one be assumed correct, the average difference of the other is 0·08 (neglecting the sign) from its magnitude as given in the catalogue. The stars compared were of all magnitudes and at all altitudes, and the comparisons were made during 23 nights some years ago. This average error of 0·08 magnitude is due chiefly to variations in the transparency of the atmosphere, to errors of observation, and to what errors there may be in the magnitudes of the stars as given in the catalogue itself.

The recent observations were commenced on February 26, and considerable variation was seen that night; and regular variations were noted up to and including March 30. But on April 7 the regularity broke down; and from May 3 to May 10 inclusive, when the observations ceased, there was no variation at all. From the 12 results obtained during this last interval it will be found that the normal magnitude of Neptune was 7·67,

with a mean apparent error of 0·05 (neglecting the signs) and a probable error of ± 0·03 for the series, assuming the magnitudes of the comparison stars to be correct.

(The curve of variation shown gives about the same result as that of 1883).

For the proper observation of these variations it is highly desirable that they should be more continuous than is possible at one place ; and instead of discussing the different points of interest connected with these observations and the resulting curve, it will be better for me to ask the aid of observers in widely differing longitudes during the opposition of Neptune in 1916, and more particularly towards the end of March and the beginning April, when the planet will be nearly stationary.— MAXWELL HALL, M.A., Kempshot Observatory, Jamaica, *Monthly Notices* R. A. S., No. 8.

CONSTITUTION OF THE INTERIOR OF THE EARTH AS INDICATED BY SEISMOLOGICAL INVESTIGATIONS.— We can say in conclusion, that the transmission of transverse earthquake waves shows that the earth is solid, at least to a great depth below the surface ; and that experiments on the deflection of the vertical show that it is quite as rigid and as viscous as steel. There are still difficulties in the interpretation of the observations, but their elucidation cannot alter the general character of the conclusions.—H. F. REID, in *Proceedings American Philosophical Society*, No. 219.

ORIGIN OF COMETS.—Professor Elis Strömgren, director of the Copenhagen Observatory, has carried out, with the aid of Mr. J. Braae, an investigation to determine whether comets come originally from interstellar space, as has been commonly supposed, or originate within the solar system. His method of research involves the backward computation of planetary perturbations for eight comets. The conclusion reached is that all comets heretofore observed have originated within the solar system.—*English Mechanic and World of Science*, No. 2631.

J. R. C.

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries.

THE DATE OF EASTER DAY

In the February number of this JOURNAL (page 96) is a very clear statement of the way in which the date of Easter in any year is found. Since then, two pamphlets have been received dealing with the same subject. The first is by Rev. Clarence E. Woodman, D.Sc., of Berkeley, Cal., and was published some years ago. The question is ably treated in it. The second publication is more extensive. It is a paper on "The Determination of Easter Day," by Dr. A. M. W. Downing, late Superintendent of the *Nautical Almanac*, which was read before the Victoria Institute, London, Eng., March 15, 1915. The paper occupies 17 pages and the discussion on it 11 more.

It would appear that, for us at least, the date of Easter depends on the definition of Easter given in the English Prayer Book, which, however, has descended from the Council of Nicæa, A.D. 325. It is difficult for us to understand why there should have been such bitter controversies over Easter as have arisen, and Dr. Downing, reviewing his lengthy explanations of multitudinous details, finds strong argument in favor of a fixed Easter. But unless there be practical unanimity amongst Christian nations, he thinks the change should not be introduced. Not only in this, but in numerous other matters can our calendar be easily improved.

PROGRAMMES FOR THE SESSION

The present writer would urge on the officers at the various Centres of the Society the advisability of preparing a programme

of the meetings for the entire session, or at least for several months in advance. Experience has shown that it is almost as easy to secure papers or addresses for six months as for one, and if the complete programme is printed, the permanence and definiteness thus added will lead to greater interest and better attendance. The President and the Secretary of the Society, I am sure, will gladly assist in arranging the programme for any Centre.

THE 100-INCH REFLECTOR FOR MOUNT WILSON

The production of the great mirror for the Mount Wilson Solar Observatory is of great interest and the present condition of the work on it is given in the July number of the *Publication* of the Astronomical Society of Pomona College, from which the following quotation is taken :—

The glass mirror for the 100-inch telescope, which is to be placed in one of the new buildings of the Mount Wilson Solar Observatory, was cast in a French foundry of the border province Lorraine, now in the possession of Germany. This, which is the original block, was not accepted, on account of flaws and bubbles, until after the makers had spent fifty or sixty thousand dollars in futile efforts to produce another, all having been broken in annealing. The block is of crown glass, green in color, and measures 101 $^{5}/_{16}$ inches in diameter and 11$\frac{3}{4}$ to 13 inches in thickness. It is parabolic in shape, having a concavity of 1$\frac{3}{4}$ inches at the centre and being thickest near the edge. The net weight is 4·8 tons, or, with the massive table supporting it, over 10 tons. The contract price for the casting in the rough was $15,000; its value when polished and silvered will be about $100,000.

The glass has been under the polishing tools for about three years, and will require another year to finish. The progress of the work is tested every morning very carefully and accurately. Before the test the mirror is kept in thick woollen blankets, in as even a temperature as heavy walls, padded doors and electric fans render possible. When it is uncovered in the morning nothing is allowed to come into proximity to the surface, as the simple stretching of a rule before it raises a distinct lump by the slight heating and consequent expansion of the glass. The overnight drop in temperature, which averages from 1 to 1$\frac{1}{2}$ degrees, causes a slight contraction and curling back, noticeable in the tests to a distance of 12 to 15 inches from the edge. Anything over that amount of change renders the minute tests inaccurate and also creates layers of stratified air in the long hallway, preventing accurate readings.

A NEW COMET

A new comet was discovered by John E. Mellish, at the Yerkes Observatory, on September 13. On October 5 its position will be R.A. $12^h\,41^m$, Decl. + 14° 26′, at the north boundary of the constellation Virgo, and it is moving about 1° south and 2° east per day. Fuller information will be given next month.

BOOKS ADDED TO THE R. A. S. C. LIBRARY

A Theory of Time and Space, by Alfred A. Robb, 1914.
Two New Sciences, by Galileo Galilei, 1914.
The Story of Our Planet, by T. G. Bonney, 1910.
Essays on the Life and Work of Newton, by A. de Morgan, 1914.
Reminiscences and Letters of Sir Robert Ball, edited by W. V. Ball, 1915.
A Day in the Moon, by Abbe Th. Moreux, 1913.
Dante and the Early Astronomers, by M. A. Orr, 1913.
Modern Seismology, by G. W. Walker, 1913.
The Essence of Astronomy, by E. W. Price, 1914.
The Riddle of Mars, by C. E. Housden, 1914.
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Cape Astrographic Zones, Vol. II.
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Expedition Norvégienne 1899-1900, by Kr. Birkeland.
Aurora Polaris Expedition, 1902-03, Vol. I.
l'Aurore Boréale, S. Lemstrom, 1886.
Auroræ and their Spectra, J. Rand Capron, 1879.
Nordlicht, vom 2 October, 1870, J. H. L. Flogel.
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Moon-Lore, by Rev. T. Harley, 1885.
Historical and Future Eclipses, by S. J. Johnson, 1896.
Copernicus, Vol. I., II., III., (all published) 1881-4.
The Scientific Papers of John Couch Adams, Vol. I., II., 1900.
Plurality of Worlds, by M. de Fontenelle, 1761.
The Observatory, Vols. I.-XXIV., to complete the set.

C. A. C.